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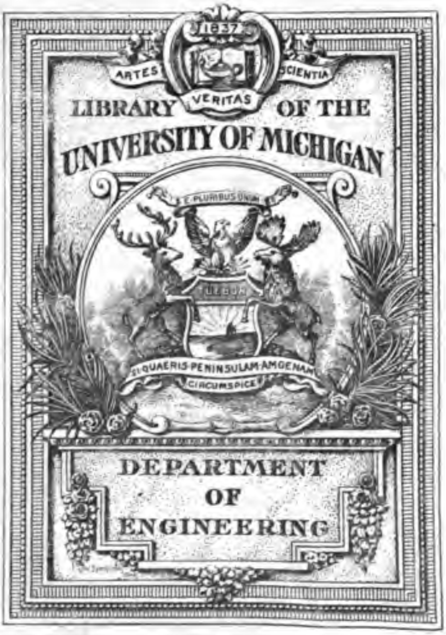
EXPERIMENTS
ON
THE FRICTION
OF
THE LEATHER COLLARS
IN
HYDRAULIC PRESSES.

CONDUCTED BY

JOHN HICK, ESQ., C.E., &c.,

OF BOLTON.

LONDON:
E. & F. N. SPON, 16, CHARING CROSS.
NEW YORK: 35, MURRAY STREET.
1884.



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EXPERIMENTS,

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THERE has long been a lack of trustworthy experiments on the ratio between the gross pressure exerted by the liquid contained in a hydraulic press and the useful pressure transmitted by its piston. The only results published up to 1867 are those by Dr. Rankine, who states that, "from experiments by Messrs. More" and himself, "it appears that the friction between a plunger and its collar is about *one-tenth* of the total effort of the water on the plunger; at all events, somewhere between one-ninth and one-eleventh." But to say nothing of the evident fact that the friction of hydraulic plungers must vary with their diameters, the following very important series of experiments we now publish show that, when the surfaces are in thoroughly *good working order*, the friction of a ram of an ordinary size is much less than one-tenth of the gross load. As will be seen, the experiments were carried out by means of an admirably ingenious and complete apparatus, the joint invention of Mr. John Hick, C.E., of Bolton (a member of the late Government committee on chain cable and anchor proving establishments), and of Mr. Lüthy, an able assistant engineer in his employ, and the inventor of an ingenious and original hydraulic packing press, which we have already described and illustrated.

We may state that the undertaking of these experiments, which have been conducted in a most scientific and thorough way, was suggested some time ago to Mr. Hick by Mr. Paget: the results have been liberally placed at this gentleman's disposal, and to his courtesy we are in turn indebted for the drawing and particulars we now publish. There is much appropriateness in the fact that this work has been conducted by Mr. Hick, as that gentleman's father, the late Mr. Benjamin Hick of Bolton, was—contrary to the popular belief—the actual inventor of the very form of self-tightening collar now universally used for hydraulic presses, and upon the friction of which under different pressures his son has now been experimenting. This interesting historical fact is acknowledged in an autograph letter, still in existence, from the son of the celebrated Bramah to the late Mr. Hick.

An examination of the engraving will show the construction of the apparatus employed. It will be at once seen that no trouble or expense was spared in obtaining accurate results, and they may be looked upon as settling for ever the character and amount of the friction of the self-tightening packings of hydraulic machinery when the surfaces are comparatively new and in good working order. In making the experiments, the first step necessary was to ascertain by a trustworthy apparatus the useful pressure exerted upon the water by the loaded plunger *p*, which, for better distinction, may be called the pressure plunger. The plunger employed was of steel, ½-in. in diameter, upon which any pressure up to 3½ tons per square inch could be brought to bear by means of a carefully graduated lever, with fixed and sliding weights, the lever and connecting links moving on hardened steel knife edges. This plunger *p* passed loosely through a brass gland, and then through a cupped leather washer. It is evident that the nett pressure on the water would be equal to the load on the plunger, minus the weight that would be necessary to overcome the friction of the plunger in the gland and the leather washer. To find the amount of this friction, a second plunger, *f*, of the same diameter as the pressure plunger, and which may be called the friction plunger, was employed. This plunger passed first through a gland and leather washer, then through a chamber filled with the fluid under the pressure, and finally again through a washer and gland. The three sets of washers and glands were made exactly alike in all their dimensions, so that each of them could fit into the place of either of the others, and that part of the friction plunger passing through the water, or the distance from washer to washer, was just double the length of that from the washer to the inner end of the pressure plunger. The pressure plunger *p* was then loaded by the lever and weight above referred to, and to this the pressure of the atmosphere on the sectional area of the plunger was added. By means of another graduated lever and weight it was then ascertained what weight was required to just move the friction plunger *f*. This weight represented the friction of two glands, two leathers, and double the length of plunger exposed to the pressure of the water, and by deducting half of it from the load on the pressure plunger, the nett pressure of the latter on the water was correctly obtained. The leather washers and glands were then changed amongst each other, in order to find whether the friction was in all of them the same, but no perceptible difference was found. One of Fogg's mercurial pressure gauges was attached to the apparatus, and the position of the mercury in the indicating tube was marked each time the nett pressure on the water had been ascertained. A correct pressure gauge having thus been obtained, the trials on the friction of leather collars on rams of different diameters were made. The apparatus constructed for this purpose consisted of a vertical framing, into which a short cylinder of different diameters could easily be fixed. From the top of the framing a steelyard was suspended, whose weight-hook was attached to the ram or plunger *p*, which passed right through the cylinder, a leather collar being provided at each end of the latter. Water was pumped into the cylinder and brought to the different desired pressures by a small force pump, the man in charge of the pump being able to watch the position of the mercury in the gauge. The lever of the pressure plunger was loaded each time to the corresponding pressure, so as to form a regulator during the operation of measuring the friction of the ram, which was easily obtained by means of the steelyard, loaded sufficiently to move the ram slowly, the weight of the ram itself being duly taken into account. Half of the weight applied to moving the ram gave the friction of one leather collar. In order to be certain that the pressure in the cylinder was the same as that indicated by the first-described apparatus and the pressure gauge, all three were placed at equal distances from each other, and connected by pipes of the same length and bore, and with the same number of bends. In order to ascertain whether the water pressing against the sides of the ram had any influence on the results, longer cylinders were made, in which the length of ram exposed to the water was several times that of the first ones, and the same collars were again used; but there was no perceptible difference in the friction under equal pressures.

FRICTION OF LEATHER WASHER FOR RAM ½-IN. DIAMETER.

Leather washer, new and stiff.			Leather used before.		Second leather.	
Gross load on ram ½-in. diam.	Friction of washer.	Friction in percentage of gross load.	Friction in lb.	Friction in percentage.	Friction in lb.	Friction in percentage.
lb.	lb.					
50	13	26·0	9·0	18·0	9	18·0
100	12·5	12·5	8·5	8·5	13	13·0
150	18	12·0	11·5	7·6	15	10·0
200	20	10·0	13	6·5	20	10·0
250	23	9·6	13·5	5·4	23	9·6
300	27	9·0	14·7	4·9	27	9·0
350	18	5·1	15·4	4·4	29	8·2
400	23	5·6	16·5	4·1	31	7·7
450	26	5·7	18	4·0	34	7·5
500	25	5·0	19	3·8	37	7·4
600	26	4·3	20	3·3	38	6·3
700	32	4·5	23·3	3·3	44	6·2
800	38	4·7	24	3·0	45	5·6
900	35	3·9	28	3·1	48	5·3
1000	33	3·3	33	3·3	48	4·8
1100	40	3·6	35·2	3·2	48	4·3
1200	50	4·1	40·8	3·4	50	4·1
1300					50	3·8

FRICTION OF LEATHER COLLAR FOR RAM 4-IN. DIAMETER.—LEATHER NEW AND STIFF; SPARINGLY LUBRICATED.

Nett pressure on ½-inch ram.	Equivalent pressure per square inch.	Pressure on 4-in. ram.	Friction of leather in lb.	Friction in percentage of load.
lb.		lb.		
37	188·7	2368	110	4·6
87·5	446·2	5600	117	2·0
132	673·2	8448	125	1·48
180	918	11520	130	1·12
227	1157·7	14528	171	1·17
273	1392·3	17472	214	1·22
332	1693·2	21248	228	1·07
377	1922·7	24128	280	1·16
424	2162·4	27136	334	1·23
475	2422·5	30400	389	1·27
574	2927·4	36736	459	1·25
668	3406·8	42752	543	1·26
762	3886·2	48768	641	1·31
865	4411·5	55360	753	1·36
967	4931·7	61888	823	1·33
1060	5406	67840	1047	1·54
1150	5865	73600	1147	1·55
		Average percentage of 15 =		1·28

FRICTION OF LEATHER COLLAR FOR RAM 4-IN. DIAMETER.—LEATHER WELL LUBRICATED.

Depth of leather touching ram.			⅞-in.		½-in.		⅜-in.	
Nett pressure on ½-in. ram.	Equivalent pressure per sq. inch.	Pressure on 4-inch ram.	Friction of leather in lb.	Friction in percentage of load.	Friction of leather in lb.	Friction in percentage of load.	Friction of leather in lb.	Friction in percentage of load.
lb.								
41	209·1	2624	56	2·13	37	1·40	39	1·50
87	443·7	5568	70	1·25	52	0·94	70	1·25
135	688·5	8640	80	0·95	78	0·91	80	0·92
180	918·0	11520	84	0·72	100	0·87	85	0·73
227	1157·7	14528	88	0·60	116	0·80	92	0·63
273	1392·3	17472	93	0·53	162	0·92	105	0·60
321	1637·1	20544	103	0·50	174	0·84	125	0·60
369	1881·9	23616	123	0·52	189	0·80	140	0·59
419	2136·9	26816	140	0·52	214	0·79	154	0·57
463	2361·3	29632	156	0·52	226	0·76	168	0·56
562	2871·2	35968	176	0·49	244	0·67	180	0·50
651	3320·1	41664	231	0·55	280	0·67	231	0·55
755	3850·5	48320	312	0·64	374	0·77	280	0·58
852	4345·2	54528	335	0·61	420	0·77	305	0·56
952	4855·2	60928	375	0·61	493	0·81	360	0·59
1052	5365·2	67328	432	0·63	558	0·83	390	0·58
1150	5865·0	73600	520	0·70				
1250	6375·0	80000	600	0·75				
	Average percentage of 16 =			0·61		0·846		0·706

Friction of Leather Collar for Ram 8-in. Diameter.

			Leather new and sparingly lubricated.		Leather used before, well lubricated.	
Nett pressure on ½-in. ram—lb.	Equivalent pressure per square inch.	Pressure on 8-in. ram.	Friction in lb.	Friction in percentage of load.	Friction in lb.	Friction in percentage of load.
87	443·7	22272	102	0·46	94	0·42
135	688·5	34560	162	0·47	145	0·42
180	918·0	46080	207	0·45	180	0·39
227	1157·7	58112	255	0·44	186	0·32
273	1392·3	69888	321	0·46	216	0·31
321	1637·1	82176	385	0·47	271	0·33
369	1881·9	94464	415	0·44	274	0·29
419	2136·9	107264	547	0·51	290	0·27
463	2361·3	118528	569	0·48	355	0·30
562	2871·2	143872	690	0·48	374	0·26
651	3320·1	166656	866	0·52	433	0·26
755	3850·5	193280	889	0·46	560	0·29
852	4345·2	218112	1047	0·48	590	0·27
952	4855·2	243712	1121	0·46	682	0·28
1052	5365·2	269312	1320	0·49	862	0·32
1150	5865·0	294400	1475	0·50	942	0·32
1250	6375·0	320000	1600	0·50	1056	0·33
	Average percentage of 17 =			0·474		0·316

RESULTS FROM THE EXPERIMENTS.

The friction increases as the pressure increases.

The friction of the leathers for rams of different diameters, if the pressure per unit of area be the same, increases in direct proportion with the diameters, or with the square roots of the respective gross loads.

The depth of the leather does not affect the friction on the ram. In several of the experiments the leathers were cut after the first trial to half the depth, and after the second trial to one-quarter the original depth, and the results, in all three cases, were practically the same. This led to the belief that the water pressing against the sides of the ram produces a friction equal to that produced by the leather per unit of area acted upon by the water. New cylinders were therefore tried, in which double the length of ram was opposed to the pressure, and the friction was again the same. It is thus evident that the depth of the leather and the length of ram in the cylinder have very little, or practically no influence on the total friction. In fact, it appears that the whole friction is produced just where the leather emerges from the hollowed part of the groove and begins to lean against the ram.

The experiments made with leather collars for a ram 4-in. in diameter, the leather being quite new and stiff and sparingly lubricated, show the greatest friction to be 1·55 per cent. of the pressure on the area of 12·56 square inches, and the smallest friction as 1·07 per cent. If we take 1·5 per cent. for a 4-in. ram under these unfavourable circumstances, we are quite on the safe side. Forty-eight experiments made with leather collars used before, and well lubricated, give an average friction of 0·72 per cent. of the pressure on a ram of 4-in. diameter. In some of these experiments the friction was as high as 1 per cent., in others as low as 0·5 per cent., the variations being 0·5 per cent.

Thirty-four experiments with a ram 8-in. diameter, show the friction to be, on an average, 0·395 per cent. of the pressure on the area of 50·26 square inches. In some of these experiments the friction was as high as 0·52 per cent., whilst in others it was as low as 0·26, the variations being only about one-fourth per cent.

If we therefore take the friction of leather collars for hydraulic presses, or other hydraulic machinery in good working condition, as 1 per cent. for rams of 4-in. diameter, or as 0·5 per cent. for rams of 8-in. diameter, we may be certain that this will meet the generality of cases.

From the experiments is deduced the following formula :—$F = D \times P \times c$, in which F = total friction of leather collar; D = diameter of ram in inches; P = pressure per square inch; C = a coefficient′; C = 0·0471 if leathers new or badly lubricated. C = 0·0314 if leathers in good condition and well lubricated. Where the pressure is given per circular inch the formula becomes :—$F = D \times P_o \times C_o$, in which F = total friction of leather collar; D = diameter of ram in inches; P_o = pressure per circular inch; C_o = a coefficient; $C_o = 0·06$ if sparingly lubricated; $C_o = 0·04$ if well lubricated.

It may be well to select an example or two, in order to render the foregoing perfectly clear.

First Example.—The friction of a leather collar of a 12-in. ram with a pressure of 5000 lb. per square inch :—$F = 12 \times 5000 \times 0·0314 = 1884$ lb. if well lubricated. The total pressure on a 12-in. ram is $= 113 \times 5000 = 565,000$ lb.; and the friction, as found above, $1884 \div 565,000 = 0·0033$, or one-third per cent.

Second Example.—The friction of the leather of a 5-in. ram, with 6500 lb. pressure per circular inch :—$F = 5 \times 6500 \times 0·04 = 1300$ lb. The total pressure on the 5-in. ram $= 25 \times 6500 = 162,500$ lb.; and the friction, as found above, $1300 \div 162,500 = 0·008$, or eight-tenths per cent.

The annexed table gives, in a compact and convenient form, the frictional resistance in percentage of